

Medieval Warming, Little Ice Age, and European impact on the environment during the last millennium in the lower Hudson Valley, New York, USA

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Abstract

Establishing natural climate variability becomes particularly important in large urban areas in anticipation of droughts. We present a well-dated bi-decadal record of vegetation, climate, land use, and fire frequency from a tidal marsh in the Hudson River Estuary. The classic Medieval Warm Period is evident through striking increases in charcoal and *Pinus* dominance from ~800–1300 A.D., paralleling paleorecords southward along the Atlantic seaboard. Higher inputs of inorganic sediment during this interval suggest increased watershed erosion during drought conditions. The presence of the Little Ice Age ensues with increases in *Picea* and *Tsuga*, coupled with increasing organic percentages due to cooler, moister conditions. European impact is manifested by a decline in arboreal pollen due to land clearance, increased weedy plant cover (i.e., *Ambrosia*, *Plantago*, and *Rumex*), and an increase in inorganic particles to the watershed.

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Introduction

Prediction of long-term drought has become a major topic at the forefront of climate change research (i.e., Trenberth et al., 2004). Droughts in the Hudson River Valley have been documented for recent centuries (Cook and Jacoby, 1977). However, millennial-scale records for the region are lacking, making it difficult to place the anthropogenic era in historical context. Longer records are crucial for estimating natural variations in climate that affect the Hudson River watershed, which provides water resources for New York City's 8 million inhabitants. Defining a detailed Hudson record of climate change to compare with regional (Cronin et al., 2003; Stahle et al.,

1988; Willard and Korejwo, 1999; Willard et al., 2003) and North Atlantic records (Bond et al., 2001; Keigwin, 1996) will improve our understanding of the forcing for these changes along the Atlantic seaboard. The unusually high sedimentation rate (avg. 0.2 cm/yr) in Piermont Marsh, New York is unique among Hudson marshes (Merley and Peteet, 2001; Newman et al., 1987; Peteet and Wong, 1999) and affords an opportunity to investigate the detailed continuous environmental history of the Hudson River watershed at bi-decadal to centennial resolution. Here, we present pollen and spores, charcoal, loss-on-ignition (LOI), and marsh sediment composition data for the last 1350 calendar yr.

Using the Piermont record, we address the following questions: (1) What was the pre-European forest and marsh composition? (2) Is a climate signal present in the shifts in pre-European vegetation and charcoal? (3) How does pre-European variability compare with anthropogenically induced change? (4) How do organic and inorganic

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sediment composition compare with vegetation shifts and the charcoal record?

Study location

Piermont Marsh (41°00'N, 73°55'W), located on the western shore of the Hudson River and approximately 40 km north of the river's mouth (Fig. 1), is one of four National Estuarine Research Reserve (NERR) sites along the river. It measures 110 ha and is bounded by Piermont Pier to the north and the Palisades sill to the west, which rises ~100 m to form Tallman State Park. Mean salinity is 6.0 ppt, and the marsh is categorized as brackish (Winogron, 1997). Two creeks, the freshwater Sparkill and the brackish Crumkill, meander through the marsh (Fig. 1b). Marsh vegetation is comprised primarily of *Phragmites australis*, but *Spartina alterniflora*, *Spartina patens*, *Spartina cynosuroides*, *Schoenoplectus robustus*, *Schoenoplectus americanus*, *Typha angustifolia*, *Iva frutescens*, *Chenopodium glaucum* (introduced), and *Chenopodium ambrosioides* (introduced) are present (Blair and

Nieder, 1993; Lehr, 1967). Due to the sharp rise of the Palisades Sill to the west, Sparkill Creek to the north, and the river contour to the south, the marsh is circumscribed with negligible marsh fringe. Because it is so limited aerially and cannot “expand” landward, the marsh area and its local wetland contribution are relatively constant over time. It is the northernmost site of *Spartina* in the Hudson Estuary, and no native *Chenopodiaceae* are found in the marsh flora today. However, dramatic changes in marsh vegetation have taken place over the last 50 yr with the advent of invasive species. *P. australis* colonies have increased their percent coverage of the marsh from 35 to 40% in 1965 to 66% in 1991 (Winogron, 1997). A detailed doctoral thesis study of Piermont Marsh hydrology demonstrates that our coring site location in high marsh *S. patens/Distichlis* is saturated throughout the tidal cycle, in contrast to the creek margin *S. alterniflora* vegetation that is not saturated during ebb tide (F. Montalto, personal communication, 2003). The lack of channel deposits in the section indicates no major changes in the courses of the marsh tributaries at our site.

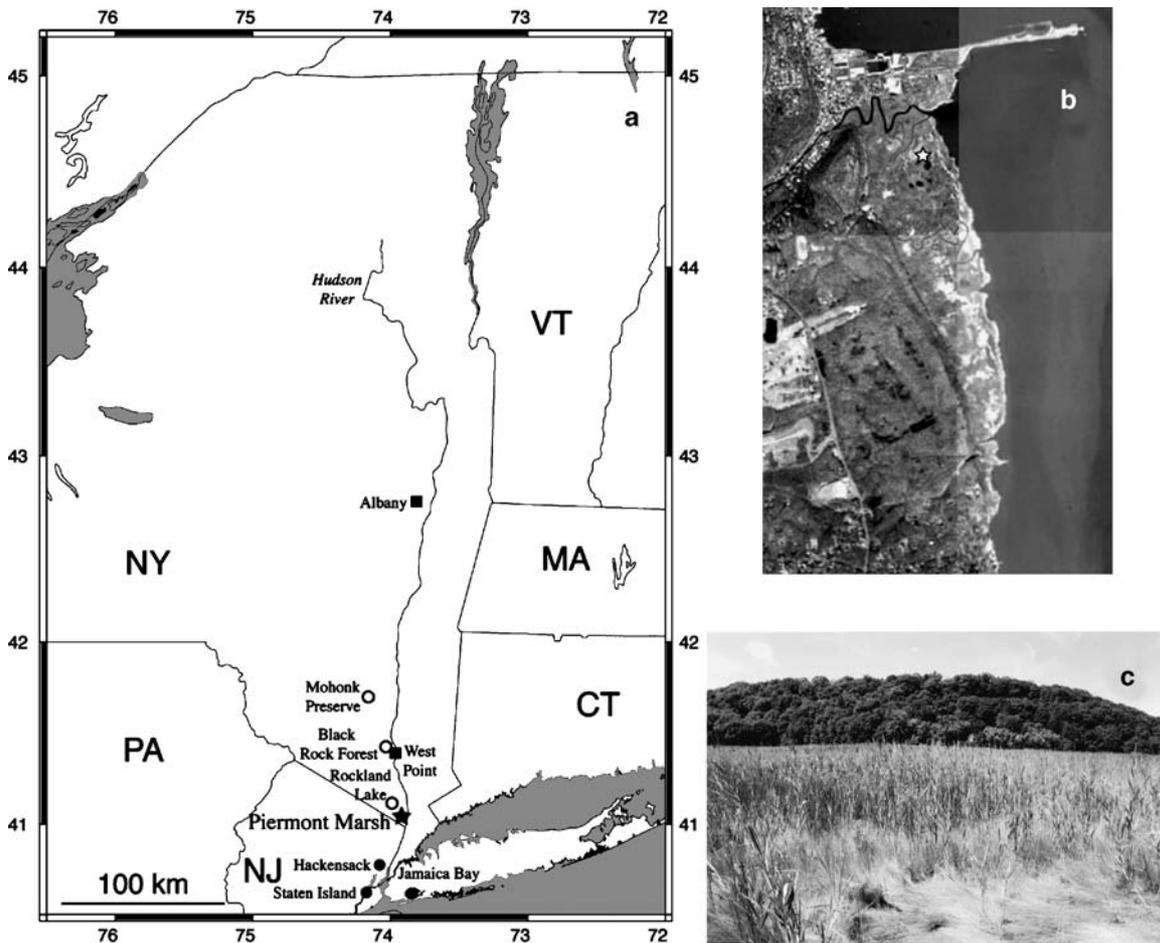


Figure 1. (a) Hudson Valley region with Piermont Marsh marked with a star. Filled circles designate regional marsh records, and unfilled circles mark upland records. (b) Aerial view of Piermont Marsh bounded to the north by the pier built in 1854. A star marks the core location. Sparkill Creek is the large tributary through the northern portion of the marsh. Tallman State Park forms the western boundary to an elevation of ~100 m. (c) Photograph of Tallman State Park from the core site. In the foreground, the remnant *Spartina patens/Distichlis* is present with *Typha* and *Phragmites* in the background. Tallman mountain rises to the west.

Local forest composition in promontory Tallman State Park reflects regional diversity, consisting of a *Quercus*–*Carya* (oak–hickory) assemblage on the more shallow soils. Northern hardwoods (*Acer saccharum* (sugar maple), *Fagus americana* (American beech), and *Betula* spp. (birch)) and southern temperate trees (*Liriodendron tulipifera* (tulip poplar), *Liquidambar styraciflua* (sweet gum)) are found on more mesic sites. *Pinus strobus* (white pine) and *Tsuga* spp. (hemlock) are also present.

Southeastern New York experiences a mixture of continental and maritime climates. Mean annual precipitation is 1080 mm. Mean temperatures for January and July in New York City are -0.4°C and 25°C , respectively (www.ncdc.noaa.gov, Central Park Observatory).

Materials and methods

The core site represents the remnant *S. patens*/*Distichlis* vegetation in the northcentral portion of the marsh (Fig. 1c). The upper 2 m was taken with a Hiller peat corer in June 2000 about 25 cm away from deeper sediment extractions (i.e., 2–3 m) using the modified Livingston piston corer (Wright et al., 1984). Due to difficulties with the Livingston corer in obtaining good recovery in the upper sediments, we used the Hiller corer for the upper 2 m. Recovery of the study intervals was 100% (both Livingston and Hiller cores). Field subsamples were refrigerated prior to analysis. Samples for pollen analysis and LOI were taken at 4-cm intervals throughout the 246 cm used in this study. Nomenclature follows FNAEC (1993). LOI was measured according to Dean (1974).

All samples for pollen analysis were prepared according to standard procedures (Faegri and Iversen, 1975; Heusser

and Stock, 1984). Pollen residues were dehydrated in alcohols and suspended in silicone oil. Pollen and spores were identified according to the reference collection at LDEO and reference books (Kapp et al., 2000; Lewis et al., 1983; Moore and Webb, 1978). For each sample, a minimum of 300 non-aquatic pollen grains were counted at $400\times$ magnification. Because *Typha* (cattail), which was tallied as an aquatic type, accounts for a large percentage of the total pollen in portions of the record, a minimum of 300 non-aquatic grains were counted for each sample to gain a more accurate vegetation signature. Pollen percentages are based on sums of arboreal and herbaceous pollen. *Typha* percentages are based on sums of arboreal, herbaceous, and aquatic pollen grains. Because the pollen sum includes upland as well as wetland taxa, interpretation of wetland development is not the object of this study. Here, we describe changes in the watershed through time. Comparison with regional lake records is possible, however, since the upland component of the core is statistically significant (~300 grains). Spore percentages are based on the sum of pollen and spores. Pollen diagrams were produced using Tilia and Tiliagraph (Grimm, 1992).

Separation of pollen to species was achieved for *T. angustifolia*, *T. latifolia*, *T. glauca*, and *Sparganium* based on the morphological work of Finkelstein (2003). *T. angustifolia* was counted as a monad, *T. latifolia* as a tetrad, and *T. glauca* as a dyad. *Sparganium* was differentiated from *Typha* based on differences in angularity described by Finkelstein (2003). *Phragmites* was separated from other Poaceae pollen grains on the basis of its small size (Clark and Patterson, 1985). The separations are featured in Figure 7.

Seventeen macrofossil samples from the top 278 cm of the core were sent to Lawrence Livermore National Labs (LLNL)

Table 1

Age ranges for 95.4% enclosed area are shown for the calendar used range in calendar calculation

Sample depth (cm)	Items analyzed	Uncorrected ^{14}C year B.P. age	Calibrated 2-sigma age range (cal year A.D.)	Calendar age (cal yr A.D.)
80–84	4 black <i>Schoenoplectus</i> seeds	145 \pm 40*	1667–1783 (46%)	1725*
88–92	woody long stem	modern		
96–100	6 black medium <i>Schoenoplectus</i> seeds	270 \pm 40*	1609–1673 (42%)	1641*
92–96	7 black <i>Schoenoplectus</i> seeds	275 \pm 40*	1608–1671 (40%)	1640*
108–112	<i>Schoenoplectus</i> stem	355 \pm 35	1539–1636 (57%)	1588
120–124	2 <i>Schoenoplectus</i> nodes	520 \pm 35*	1391–1444 (86%)	1418*
132–136a	1 sedge node, 1 <i>Eleocharis</i> seed	515 \pm 45	1386–1454 (79%)	1420
132–136b	1 <i>Dirca</i> -type seed, 5 yellow <i>Schoenoplectus</i> seeds	600 \pm 60*	1291–1425 (100%)	1358*
140–144	2 sedge nodes, 1 woody fragment	455 \pm 35	1408–1487 (100%)	1448
148–152	1 black <i>Schoenoplectus</i> , 2 yellow <i>Schoenoplectus</i> seeds	660 \pm 70*	1245–1417 (100%)	1331*
168–172	3 charcoal pieces, 1 large <i>Schoenoplectus</i> seed	70 \pm 40	1876–1917 (44%)	
176–180	2 black medium <i>Schoenoplectus</i> seeds, 3 <i>Eleocharis</i> seeds, 1 white <i>Carex</i> seed	785 \pm 45*	1179–1294 (100%)	1237*
184–188	1 <i>Cladium</i> , 1 <i>Carex</i> , 2 yellow <i>Schoenoplectus</i> seeds	1035 \pm 45*	894–1043 (92%)	969*
188–192	2 sedge nodes, 2 woody fragments	1300 \pm 35	660–777 (100%)	719
192–196	2 charcoal stems	1030 \pm 40	940–1043 (84%)	992
214–216	1 <i>Cladium</i> , 5 yellow <i>Schoenoplectus</i> seeds	1210 \pm 40*	758–897 (81%)	828*
276–278	2 <i>Polygonum</i> seeds	1580 \pm 80*	336–640 (98%)	488*

Relative percent area represented by the calendar range is shown in parentheses (.). Selected dates are marked by an asterisk (*).

for AMS-radiocarbon dating. The depths and types of macrofossils for all dated samples are presented in Table 1. Sediment accumulation rates were calculated using linear interpolation between the ¹⁴C dates (Fig. 2). The core top was estimated at 0 cal yr B.P. (the core was obtained in A.D. 2000, calendar dates obtained with CALIB 4.4 were adjusted from A.D. 1950) because there was no indication of disturbance.

Use of microscopic charcoal as a fire indicator has been the topic of numerous studies (e.g., Clark, 1988; Tinner and Hu, 2003). Clark (1988) examines the controversies of using pollen-slide charcoal counts and, using particle motion theory concludes that the small charcoal particles counted in most studies (5–10 μm) yield ambiguous charcoal records. In this study, charcoal pieces >50 μm × 10 μm (500 μm²) were counted along with pollen grains and exotic *Lycopodium*. The size criterion was chosen to avoid confusion of microscopic charcoal with opaque mineral material, which is typically <50 μm in one dimension (Clark and Patterson, 1984; Parshall and Foster, 2002). The criterion is also in agreement with Clark’s (1988) assertion that thin-section charcoal (minimum size = 50 μm) better represents local fire events (Clark and Robinson, 1993). We note that those intervals with more charcoal >50 μm also had more small charcoal fragments (<50 μm). Although charcoal is primarily transported by wind and water, the size used in this study reflects particles from local origin (<20 km if convection column reaches 1000 m; Clark, 1988). Identified macrofossil charcoal in the samples at various intervals (D. Peteet, unpublished data, 2002) supports local fires in the marsh itself. However, because the marsh floods twice a day, it is possible that some of the wood charcoal reflects fires in the larger watershed.

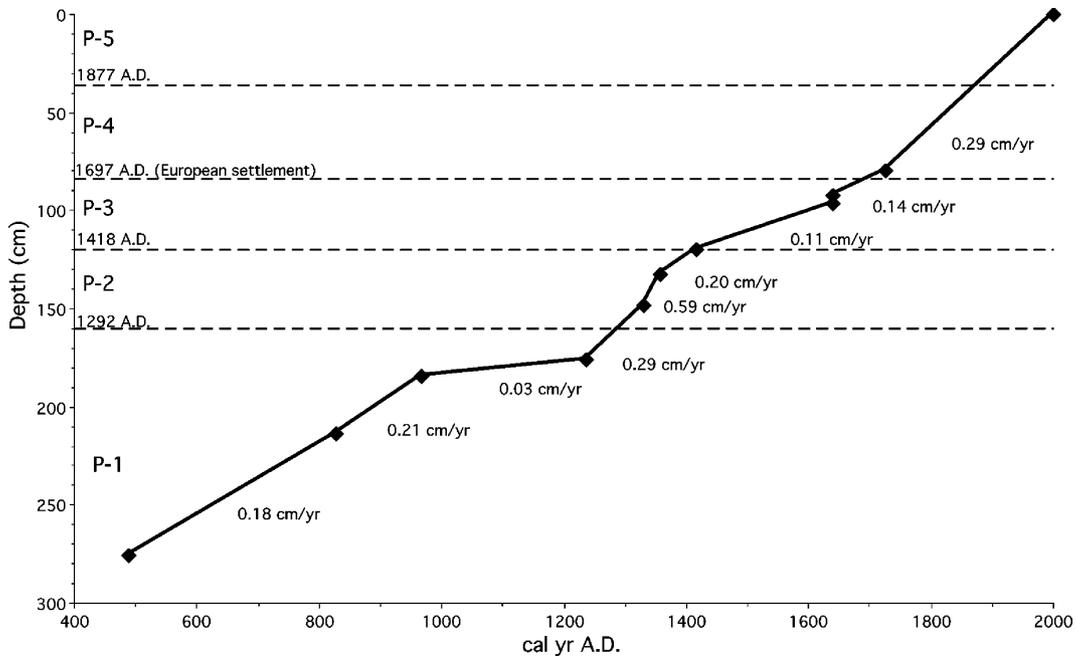


Figure 2. Linear interpolation of sedimentation rates for the Piermont Marsh core. Calculation of sedimentation rates assumes constant accumulation between dated layers.

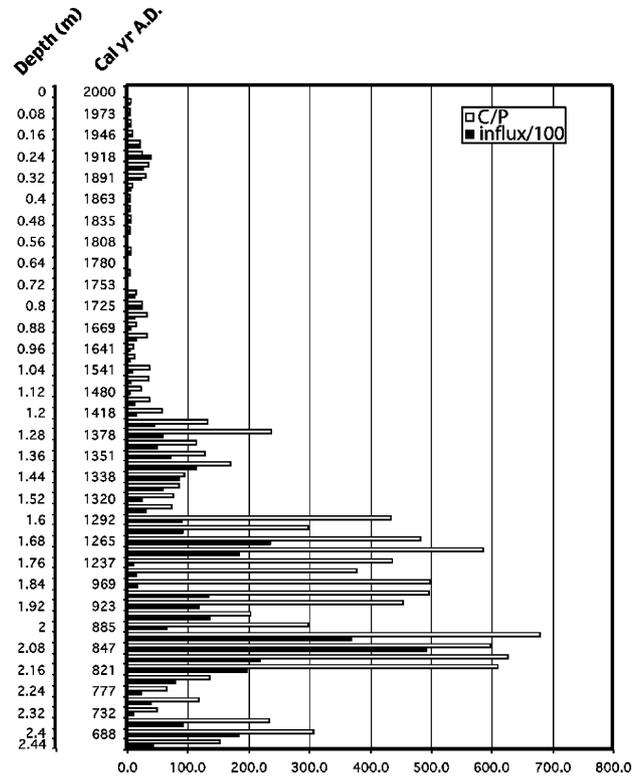


Figure 3. Comparison of charcoal influx data ($\mu\text{m}^2 \text{cm}^{-2} \text{yr}^{-1}$) with C/P ratios (charcoal area / # pollen grains). Linear regression of the two datasets yields $r^2 = 0.61$.

Charcoal influx and charcoal/pollen ratios (C/P) were calculated for the study interval. Linear regression of the two calculations yields $r^2 = 0.61$, but both are shown for ease of comparison with other studies (Fig. 3). Calculation

of C/P ratios is conservative because the only criterion for counting was a minimum area of 500 μm^2 . C/P ratios were calculated for each sample as follows:

$$C/P = \frac{\text{charcoal area}(\mu\text{m}^2)}{\#\text{pollen grains}}$$

Results

Lithology, radiocarbon dating, age model, and sedimentation rates

The lithology for the study section is composed of peat, muck, and mucky peat (Fig. 4). Although the coring site is 100 m from the current course of Sparkill Creek, there are no channel deposits of coarser grained sediment in the core. The absence of any channel deposits supports continuous peat accumulation.

Radiocarbon dates from the core are mostly in stratigraphic order (Table 1). Two of seventeen dates were unusable due to contamination (88–92 cm, 168–172 cm). Ten of the remaining fifteen dates were used in the age model. We did not include dates from 108–112 cm, 132–136a cm, 140–144 cm, 188–192 cm, and 192–196 cm, which were omitted in favor of using marsh seed dates. Identified marsh seeds produced in situ have tough outer coats, impermeable to carbon contamination. Seeds take their carbon from the atmosphere and reflect the annual production rates of ^{14}C more accurately than bulk sediment dates, woody fragments, or charcoal stems. While macrofossils are subject to water transport to be incorporated in the peat profile, the non-seed material (i.e., wood and charcoal stems) may be contaminated by old carbon from the watershed

itself, a correction that can be as great as 1000 yr in the Hudson River (Olsen et al., 1978). Radiocarbon dates were converted to calibrated “calendar” dates using CALIB 4.4 (Stuiver and Reimer, 1993). Calendar age range is shown for 95.4% enclosed area (2-sigma).

Because large changes in ^{14}C production for the time period spanned by this study can result in chronological uncertainties, several possible relative age ranges exist. Thus, dates selected for the age model were chosen on the basis of high relative area under the probability distribution within the 95.4% area enclosed. Cultural horizons, the most common being the increase in *Ambrosia* associated with permanent settlement, can be correlated to dates from historical records and have been used in studies focusing on more recent time scales (Brugam, 1978; Brush et al., 1982; Clark and Patterson, 1984; Davis, 1983; Davis et al., 1980; Fuller et al., 1998; Maenza-Gmelch, 1997; Russell et al., 1993; Willard and Korejwo, 1999). This adds to the chronologic control for this study.

Pollen assemblages, organic content, and charcoal

The core was divided into five pollen zones based on visual inspection. Objective zonation using CONISS confirms zone selection (Grimm, 1992). Specific zone age is based on the assumption of a constant accumulation rate between ^{14}C -dated layers. Ages calculated by linear interpolation are marked with an asterisk (*).

Zone P-1

Pinus–Quercus zone (A.D.~*653–*1292; 246 to 160 cm). *Pinus* and *Quercus* are the major pollen types (Fig. 4). *Pinus* is dominant and is composed of both haploxylon and diploxylon types, with broken grains preventing differ-

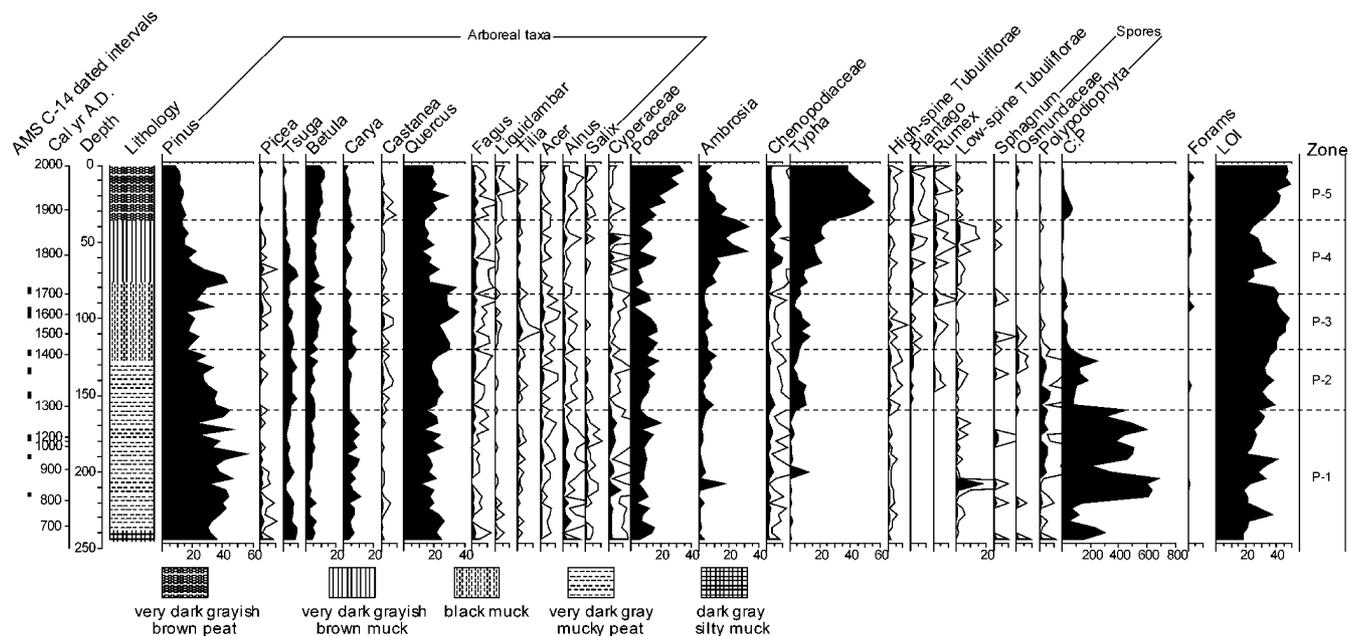


Figure 4. Percent data for Piermont Marsh pollen and spores. C/P ratios, forams, and LOI values are also shown. Exaggeration lines (5×) are shown for minor taxa.

entiation. Minor arboreal inputs from *Tsuga*, *Betula*, and *Picea* (spruce) are observed. *Carya* reaches its maximum percentage (11%). Polypodiophyta percentages, although small, are consistently present in this zone.

Herbaceous pollen accounts for 10 to 14% of the pollen sum. *Ambrosia* and low-spine Tubuliflorae exhibit sharp peaks at 208 cm. The total pollen accumulation rate (influx) reaches minimal values for the entire sequence (Fig. 5). LOI is variable, ranging between 20 and 40%. Inorganic sediment mass contributions range from 0.16 to 0.72 g, a maximum for the study interval (Fig. 6). Organic mass contributions are much more constant, ranging from 0.10 to 0.17 g. C/P ratios are striking in magnitude when compared to the rest of the core; maximum values (135–679) are maintained throughout the zone (Figs. 4 and 6).

Zone P-2

Pinus–Quercus–Typha zone (A.D. ~*1292–1418; 160 cm to 120 cm). *Pinus* (16 to 36%) and *Quercus* (18 to 30%) are the dominant arboreal species, with *Pinus* declining to the top of the zone. Rises in Poaceae (6–18%), *Ambrosia* (3–11%), and *Typha* (3–11%) percentages are observed. *Plantago* and *Rumex* appear for the first time. Polypodiophyta are consistently present and reach a maximum of 7.8% during this interval.

LOI values for this zone increase and are less variable than in the previous zone, ranging from 28 to 39%. The inorganic sediment fraction mass is also less variable than in the previous zones (0.18 to 0.29 g), while the organic contribution remains similar to previous zones (0.10 to 0.14 g). C/P

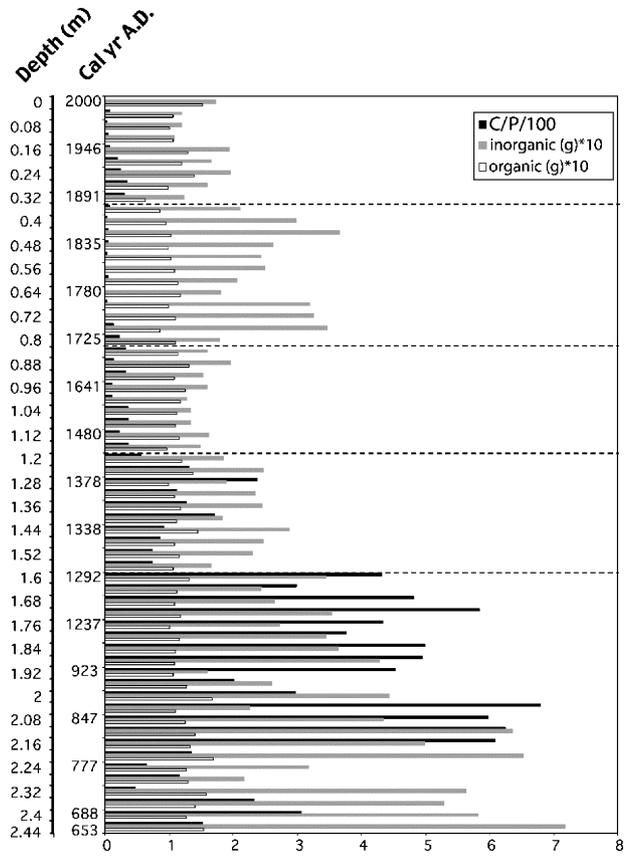


Figure 6. Sediment component masses and C/P ratio data for the Piermont Marsh core. Inorganic and organic fractions are based on dry sample mass. Horizontal dashed lines mark pollen zones for comparison with pollen diagrams.

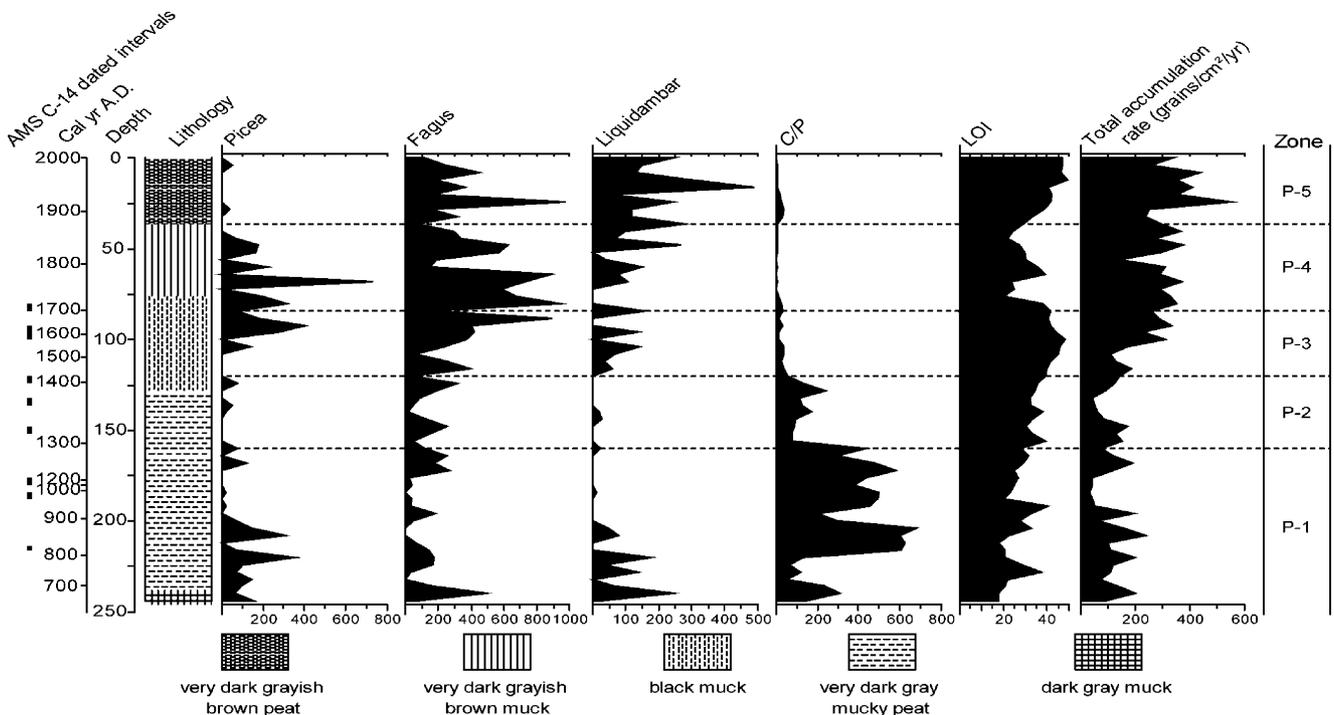


Figure 5. Selected pollen influx data mentioned in the text for Piermont Marsh with C/P ratios and LOI data.

ratios are moderate and much lower than zone P-1 (57–237). Total pollen influx is variable and reaches values almost as low as those observed in the high charcoal zone, P-1.

Zone P-3

Quercus–Pinus–Betula zone (A.D. ~1418–*1697; 120 cm to 84 cm). For the first time in the record, *Quercus* (23 to 36%) is present in equal and higher percentages than *Pinus* (16 to 33%; Fig. 4). *Pinus* percentages increase slightly at the top of the zone, as does *Picea*. *Betula* also increases slightly (up to 12%) from zone P-3. Polypodiophyta spores decline dramatically to zero.

C/P ratios continue to decrease from P-3 (11–37). LOI increases to a zonal peak of 48% at 96 cm. Both inorganic and organic fraction masses are relatively consistent for this zone. Inorganic mass ranges from 0.13 to 0.20 g, and organic mass ranges from 0.10 to 0.13 g. Decreasing C/P ratios complement the total pollen influx increase shown from the bottom to the top of the zone.

Zone P-4

Pinus–Quercus–Ambrosia–Typha zone (A.D. ~*1697–*1877; 84 to 36 cm). *Pinus* and *Quercus* again are the dominant arboreal species, but both genera drop significantly as *Ambrosia*, *Typha*, and Poaceae increase (Fig. 4). The date of this zone is based on consistently high levels of *Ambrosia* (10%) and corresponds to the timing of successful European settlement (A.D. 1681). Within the zone, there is a shift among major pollen types, as herbaceous taxa account for 10 to 51% of the pollen sum. *Rumex* and *Plantago* are more consistently present during this time, and species other than *Ambrosia* from the low spine Tubuliflorae family are consistently seen. A maximum is reached for Chenopodiaceae (10%) mid-zone. *Pinus* decreases sharply from 43 to 13%, *Quercus* drops to an average of ~15%, and *Betula* fluctuates between 4 and 12%.

LOI values generally drop and are more variable (averaging ~30%) than in the previous zone and peak at 56–60 cm. Inorganic sediment masses increase in this zone with peaks at 44 and 76 cm, ranging from 0.18 to 0.36 g (Fig. 6). Organic masses decrease slightly from the previous zone and range from 0.06 to 0.12 g. C/P ratios reach minimum values for the record (0–31).

Zone P-5

Quercus–Typha–Poaceae zone (A.D. ~*1877–2000); 36 to 0 cm). Major pollen types are *Typha* (38 to 55%), *Quercus* (17 to 29%), and Poaceae (11 to 35%). *Ambrosia* (4 to 18%) drops off as the previously mentioned taxa increase. *Typha* percentages drastically increase. *Pinus* is still present in small amounts (9–16%), and *Betula* reaches a plateau of ~10% in the zone, which is a maximum for the entire study section. *Plantago* reaches a maximum value of 3% at the surface, and *Rumex* is still present.

LOI values increase to values similar to those in zone P-4. Inorganic masses drop abruptly from the previous zone

with values from 0.20 to 0.11 g. Organic masses increase slightly but remain similar to those in previous zones (0.10 to 0.15 g). C/P ratios are higher than zone P-4 and are comparable to that seen in zone P-3 but decrease toward the surface.

Discussion

The Piermont Marsh changes in lithology and LOI, pollen and spores, charcoal, and macrofossils along with ¹⁴C stratigraphy provide us with a high-resolution environmental history that is a primary record for this region. Additional cores from the marsh and nearby Hudson marshes (work in progress) will refine our understanding of the strengths and limitations of this unique site. Major changes in climate and human impact characterize the record.

Pre-European Pinus–Quercus forest with droughts (A.D. ~*653–*1292)

Dominant forest trees at ~A.D. 653 were *Pinus* and *Quercus* species. *P. strobus* was probably the dominant *Pinus* species as it is today, but *P. rigida* and *P. resinosa* were also likely present, as evidenced by both haploxylon and diploxylon pollen grains. While both *P. rigida* and *P. resinosa* are found in the modern regional landscape, *P. rigida* is more common. Other records from the lower Hudson Valley do not show the prevalence of *Pinus* (mean of 35%) seen in the Piermont record (Fig. 4), but the record from a Staten Island marsh (D.S. Kleinstein, unpublished data, 2003) does show values as high as 25%. In contrast, modern small lake records in the region (Loeb, 1989; Maenza-Gmelch, 1997) do not indicate *Pinus* percentages above 10%. This suggests general site differences with more *Pinus* growing in the watershed than local lakes reveal, or an artifact of more fluvial and aerial transport of *Pinus* pollen to the marshes than to more protected small lakes. Future analysis of surface reference samples for modern pollen–vegetation relations will address this question. *Quercus* includes at least six species (*Q. alba*, *Q. rubra*, *Q. velutina*, *Q. bicolor*, *Q. prinus*, and *Q. coccinea*), which are modern components of the Hudson River Valley (Little, 1971).

Loeb (1989) examined modern surface samples from several nearby lakes, and the most proximal to Piermont, Rockland Lake, shows a *Quercus*-dominated forest with values varying between 30 and 50% at the surface, contrasting with the Piermont record of 20% due to dilution by local marsh taxa such as Poaceae. While *Quercus* is typically one of the dominant arboreal taxa in most regional records (Buell et al., 1966; Carmichael, 1980; Clark and Patterson, 1985; D.S. Kleinstein, unpublished data, 2003; Maenza-Gmelch, 1997; Margraf, S.E., unpublished data, 2003; Russell, 1981), co-dominant species differ. To the north at Mohonk, NY (S.E. Margraf, unpublished data,

2003) where mean July temperature is 2°C colder than the Piermont area, *Betula* is the dominant taxon as it is in some Massachusetts lakes to the northeast (Fuller et al., 1998). *Betula*, *Fagus*, *Tsuga*, and *Acer* were also present in small amounts at Piermont. The minor presence of *Castanea* at this time contrasts with other upland records from NY (Maenza-Gmelch, 1997; S.E. Margraf, unpublished data, 2003) and Connecticut (Brugam, 1978; Davis, 1969) where *Castanea* averages 10%.

Noteworthy increases in *Picea* are seen here as conditions become dry and increased erosion from the north probably deposited more buoyant grains such as *Picea* (Fig. 4). *Carya* expands in the upper half of the zone, suggestive of warmer temperatures. *Carya* requires less moisture than other warm temperature indicator genera (i.e., *Castanea*) (Fowells, 1965). Shuman et al. (2004) demonstrate that mid-Holocene *Carya* expansion in New England occurred when temperatures were almost as warm as today based on hydrogen–isotope ratios. Forest and/or marsh fires were dominant in Piermont during this interval, as evidenced by high charcoal influx (Fig. 3). Pollen influx in the marsh is minimal, further suggesting loss of biomass and drier conditions leading to increased upland erosion which was then deposited in the marsh (Fig. 5). The increase in charcoal influx suggests several possible causes: (1) increased fire due to Native American activity, (2) increased river transport of buoyant material such as charcoal, or (3) a climate shift resulting in increased mortality due to drought that favored fire.

Native Americans often settled in river valleys, and those living in southern New England subsisted more on agricultural practices than from hunting alone (Cronon, 1983; Williams, 1989). Maintenance of fields and grasslands for berries and wild game prior to European settlement is a possible cause for increased burning (Williams, 1989), but large wildfires started by Native Americans are considered unlikely (Day, 1953; Russell, 1983). Natural disturbance or land clearance and maintenance by Native Americans in the large river valleys of northeastern North America (Day, 1953; Williams, 1989) would allow light-loving species such as *Ambrosia* to sporadically thrive prior to European settlement.

It is possible that changes in water transport played a role in the increase in charcoal and buoyant pine pollen during the time period coincident with the Medieval Warm Period (MWP). However, changes in the watershed source over the last millennium prior to European impact are unlikely, as geologic factors are insignificant on this time scale. We thus favor a climatic interpretation for the changes that take place in the Piermont record from ~A.D. 795–1290, corresponding to the timing of the Medieval Warm Period as defined by Lamb (1982) to be ~A.D. 800–1200 in Europe and Greenland. Drier conditions at the landscape scale are supported by *Pinus* dominance, large increase in charcoal influx, and low pollen influx. Because the size criterion used for quantifying charcoal is based on sizes that yield more

local information, the peaks in the record indicate local fires (within 20 km). The expansion of more southern temperate taxa such as *Carya* and *Liquidambar*, along with the decline of *Betula*, *Tsuga*, and *Alnus*, suggests warmer and drier conditions. Isolated peaks in Poaceae and *Ambrosia* percentages also support the drought/increased fire hypothesis, as these taxa are more likely to colonize the landscape after a disturbance such as fire. The abundance of *Ambrosia* pollen (17%) at 208 cm is noteworthy since percent values of 10% have been related to dates of European settlement; this sharp increase in *Ambrosia* is indicative of disturbance associated with increased charcoal (Clark, 1986; Clark and Patterson, 1985; Russell and Davis, 2001; Russell et al., 1993). Other nearby pollen studies show significant presence of *Ambrosia* (or *Iva*) much earlier than the first date of European settlement, further supporting the disturbance hypothesis for these early peaks (Carmichael, 1980; Clark, 1986). During this time, the only pollen types showing significant increases in both percent and influx data are Polypodiophyta and *Salix*. Increases in *Salix* and Polypodiophyta during this interval may reflect colonization of these species on expanding riverbanks as water level dropped.

Regional studies along the North Atlantic seaboard support our drought/fire hypothesis of the major shifts in Piermont Marsh. To the south along the Atlantic seaboard, Brush (1986) found warmer, drier conditions with increased charcoal from A.D. 1000–1200 in cores from Chesapeake Bay. Cronin et al. (2003) used Mg/Ca based temperature reconstructions of ostracode shells to identify the first half of the MWP in their record. Sustained periods of drought from A.D. 1000 to 1300 are noted using tree-ring reconstructions from North Carolina (Stahle et al., 1988). While the periods of drought in each of these studies corresponds to times of high charcoal in Piermont, the record presented here reflects the full length of the classic MWP.

To the north, lake records from Black Rock Forest also demonstrate increased fire during this interval prior to European impact (Maenza-Gmelch, 1997). Several ponds in central Massachusetts show increased C/P ratios during this interval; these locations are located in upland areas on poorer soils and are probably more sensitive to drought (Fuller et al., 1998). Other lake charcoal studies from the eastern US show that climate is an important influence on fire regimes (Clark and Royall, 1996; Parshall and Foster, 2002; Swain, 1973). However, many lower-resolution records from the NE US do not capture the importance of fire on the landscape during the MWP (Parshall et al., 2003; Russell et al., 1993).

Other North American records of the MWP have been demonstrated in the southwestern US (Cook et al., 2004; Stine, 1994). Midwestern US lake and dune records have also shown periods of drought during the MWP (Fritz et al., 2000; Mason et al., 2004). Recent speleothem studies record high ^{18}O values corresponding to the MWP in New Zealand

(Williams et al., 2004). Documenting the global extent of this warm interval is important for understanding hemispheric linkages (Broecker, 2001).

Forest Transition (A.D. ~*1292–1418)

During the next century, we see increases in more mesic species (*Tsuga*, *Fagus*) as *Pinus* and Chenopodiaceae decline. *T. angustifolia* is present consistently at the site, possibly indicating fresher conditions (Fig. 7). While this local marsh change may add more organic material to deposited sediment, a sharp decrease in inorganic input is evident from the raw data (Fig. 6). The plateau in organic mass and the corresponding decrease in inorganic mass leads us to conclude that the relative increase in LOI is due not to an increase in organic material but to a decrease in inorganic material. Charcoal influx decreases suggesting less fire, and the subsequent landscape stabilization encourages revegetation, reducing erosion, and the inorganic input to the marsh (Fig. 6). Relative organic content (LOI) rises as cool and moist conditions prevail with the onset of the Little Ice Age (LIA; A.D. 1400–1850; Lamb, 1982).

Little Ice Age and early European settlement (A.D. ~1418–*1697)

An expansion of *Quercus* and corresponding stabilization of *Pinus* characterizes this pre-European forest. Expansion of *Tsuga* forests indicates more available moisture, and the spread of northern genera such as *Picea* and *Fagus* suggests cooling, coinciding with the occurrence

of the LIA. Lower charcoal influx (Fig. 3) and mineral content (Fig. 6) in the sediment indicate less drought stress and erosion of the landscape, further evidencing the presence of the LIA. Continued expansion of Poaceae and *Ambrosia* indicates disturbance by Native Americans and early Europeans. The Tappan tribe that occupied the surrounding area during this time period developed a strong agricultural and fishing society, complemented by winter hunting and trapping (Haagensen, 1986).

European settlement: Forest clearance, industry, and beginning of permanent agriculture (A.D. ~*1697–*1877)

The area was colonized by Europeans in A.D. 1681 (Haagensen, 1986). Thus, it is reasonable to attach a date of A.D. *1697 to the marked, consistent *Ambrosia* rise. The *Ambrosia* rise is found in many pollen records from the northeast (Brugam, 1978; Carmichael, 1980; Clark, 1986; Clark and Patterson, 1985; Davis, 1969; Maenza-Gmelch, 1997; Russell and Davis, 2001; Russell et al., 1993). Other weedy species such as Chenopodiaceae, *Plantago*, and *Rumex* (Fernald, 1970) are also seen in greater abundance during this time. Decreases in the abundance of trees characterize the settlement period. Early settlers cleared the land for farms, homes, fuel, and ships. Dynamic changes in the local forest after settlement took place as *Quercus* and *Pinus* were felled for construction, fuel, and defense (masts, forts, etc.). *Quercus*, *Carya*, and *Castanea* were used for structures and fuel.

The Revolutionary War undoubtedly had a large impact on population and vegetation in this area. Vegetated shores along the river such as Stony Point and Fort Montgomery near the Bear Mountain Bridge were cleared for battles. Forests were burned to produce charcoal used in iron production (Cronon, 1983). The population of this area grew at times with increases in troop numbers (Haagensen, 1986). Rockland County, where Piermont Marsh is located, supported a population of 6000 in a 1790 census, an increase from the tally of 219 inhabitants in 1693 (Cole, 1884). This increase is probably a direct result of increased occupation during and after the war. Historic records of cold, snowy winters attest to the harsh conditions the people endured (Schechter, 2002).

The modern period of deforestation to reforestation: A.D. ~*1877–2000

Deforestation on the landscape is dramatic with reduced presence of *Pinus* and *Tsuga*, as the *Quercus* forest recovers slightly in the 20th century. Much wood was needed in New York City to power steamboats and engines, and a convenient source would likely be this area because of proximity and easy river transport (Haagensen, 1986). A local brick factory in Haverstraw manufactured over 32 million bricks in 1883, which required enormous amounts of wood (Cole, 1884). The tanning industry used bark from

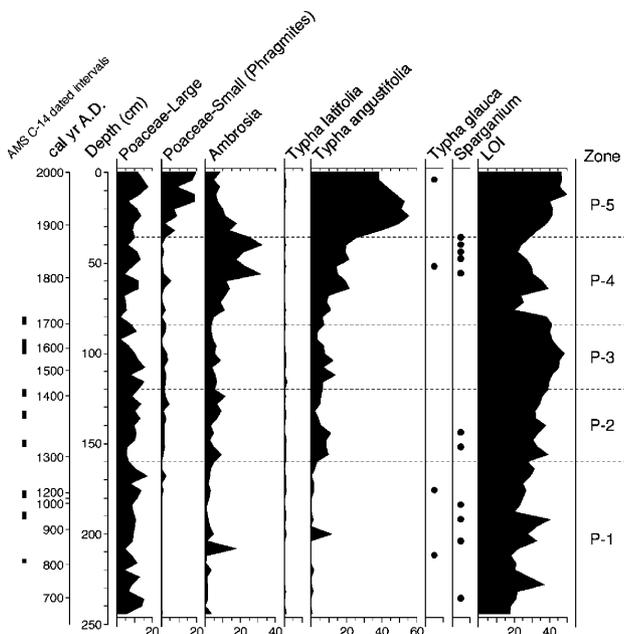


Figure 7. Pollen size separation data for Poaceae and *Typha*. Large Poaceae grains represent native marsh grasses, while small Poaceae grains correspond to *Phragmites* establishment.

Tsuga, accounting for its dramatic decrease (Russell et al., 1993). *Betula*, a disturbance species and less economically viable, becomes more abundant during this time, a trend observed in other NE US sites (Russell et al., 1993). These forest trends are observed in other areas of the northeast and likely indicate reforestation of cleared lands (Russell et al., 1993). In the last decade, the woolly adelgid has plagued *Tsuga* stand in the NE US, causing further decrease in this forest species (Orwig et al., 2002).

The anthropogenic influence emerges clearly in local marsh vegetation dominated primarily by Poaceae and *Typha*. A steady rise in Poaceae is visible as trees are felled but reaches greatest abundance during the last several decades, a pattern also visible in Jamaica Bay and Saw Mill Creek, which are NY marshes (Fig. 1a; D.S. Kleinstein, unpublished data, 2003; Peteet and Liberman, 2001) as well as in the Hackensack Meadowlands, New Jersey (Fig. 1; Carmichael, 1980). Recent Poaceae expansion is due to *Phragmites* invasion since the 1960s (Winogron, 1997; Wong and Peteet, 1999). Clark and Patterson (1985) separated Poaceae based on size in a Long Island tidal marsh. Their size criteria were used in this study and support an increase in *Phragmites* in recent decades (Fig. 7). Size separation data also show the presence of *Phragmites* prior to European settlement, adding valuable information to the controversy of the native/introduced status of *Phragmites*. While native *Phragmites* has been present in the local marsh landscape over time, its recent dominance is attributed to introduced varieties that vary genotypically from the native types (Saltonstall, 2002).

Typha abundance in the marsh is maximal during the 20th century and is probably due to increases in eutrophication both from local and watershed-level nutrient inputs. Finkelstein (2003) separated *Typha* species based on morphology. *T. latifolia* has traditionally been thought of as a native species, while *T. angustifolia* is viewed as possibly an introduced species. The presence and dominance of *T. angustifolia* in the Piermont record indicate that *T. angustifolia* is not an introduced species. The presence of *T. angustifolia*/*Sparganium* is also documented from the Hackensack Meadowlands (Carmichael, 1980). Moreover, the presence of the hybrid *T. glauca* ~A.D. 800 indicates that *T. angustifolia* was present early enough for hybridization to occur.

Marsh sediment composition and watershed implications

Changes in organic and inorganic components in the Piermont Marsh sediments are intriguing. The input of organic material has been relatively constant throughout (0.06 to 0.15 g), while the inorganic component has drastically decreased (from 0.72 to 0.11 g) from A.D. 653 to the present (Fig. 6). This inorganic decline is complemented by a relatively consistent proportion of water (62 to 88%) in the samples, suggesting that de-watering of clays is not a factor for these changes. If core compaction played a role in sediment characteristics, higher pollen influx would

be evident in the deeper sections of the record (Brugam, 1978). Pollen influx is actually much lower at the base of the record than at the surface, indicating that compaction is minimal.

The gradual decrease in inorganic material upcore suggests several possible mechanisms. Climate change probably accounts for the signature of watershed erosion to the marsh because the MWP with drought and high fire records large inorganic inputs while the cooler, wetter LIA inputs to the marsh are minimal. A dry, burned landscape is more susceptible to removal of inorganics than one that is heavily vegetated, further supporting the drought hypothesis. Another possibility is relative sea level fluctuation, as Piermont creek banks receive more inorganic matter than the internal high marsh. Tectonism could also have affected relative sea level, as the area is faulted (Newman et al., 1987).

Humans have also affected erosion. European impact is clearly marked as an abrupt increase in inorganic content from about A.D. 1700 to 1875, but the magnitude of the rise is not equivalent to MWP inputs. This landscape clearance that resulted in higher inorganic supply parallels the increases in weedy species. Previous estuarine work has shown drastic increases in sedimentation rates after land clearance, due to increased runoff and erosion (Brush, 1984, 1989; Brush et al., 1982; Neubauer et al., 2002; Pasternack et al., 2001).

Subsequent declines in Piermont Marsh inorganic content in the twentieth century support revegetation of the watershed. Eutrophication has especially influenced the expansion of *Typha* and *Phragmites* on the marsh itself.

Conclusions

- (1) Pollen stratigraphy from Piermont Marsh reveals the pre-European forest composition (A.D. 653–1697) as *Pinus*–*Quercus* forest with minor inputs from *Tsuga*, *Betula*, and *Carya*.
- (2) The MWP is present from A.D. 800 to 1300 as indicated by increases in *Pinus* and *Carya*, declines in *Quercus*, the inconsistent presence of *Picea*, decreases in drought-sensitive species (*Tsuga*, *Betula*, *Alnus*), and large increase in fire. Higher inorganic content (erosion) and low pollen influx during this interval further support the drought hypothesis.
- (3) The subsequent LIA (A.D. 1400–1850) is evident from *Picea* peaks, increases in *Tsuga* and Cyperaceae, and minimal erosion (low inorganic component) of the watershed.
- (4) European impact in the 18th century is striking with increases in local marsh species such as *Typha*. The spread of weedy genera such as *Ambrosia*, *Plantago*, and *Rumex* indicates upland disturbance until the 20th century, when they decline with reforestation.

- (5) Charcoal abundance is greatest coincident with the MWP and suggests that fire frequency is mediated primarily by climate (drought) in the Hudson watershed.
- (6) Inorganic inputs to the marsh are highest at the initiation of this record, decreasing toward the present. European impact shows resurgence in the inorganic fraction, resulting from changes in land use. Continued research on a suite of Hudson River marshes will further elucidate the influences of drought and fire in the Hudson Valley.

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